Inclusive Measurements with MINERνA

NuFact 2011 - August 4, 2011 - Geneva, Switzerland

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for the MINERνA collaboration

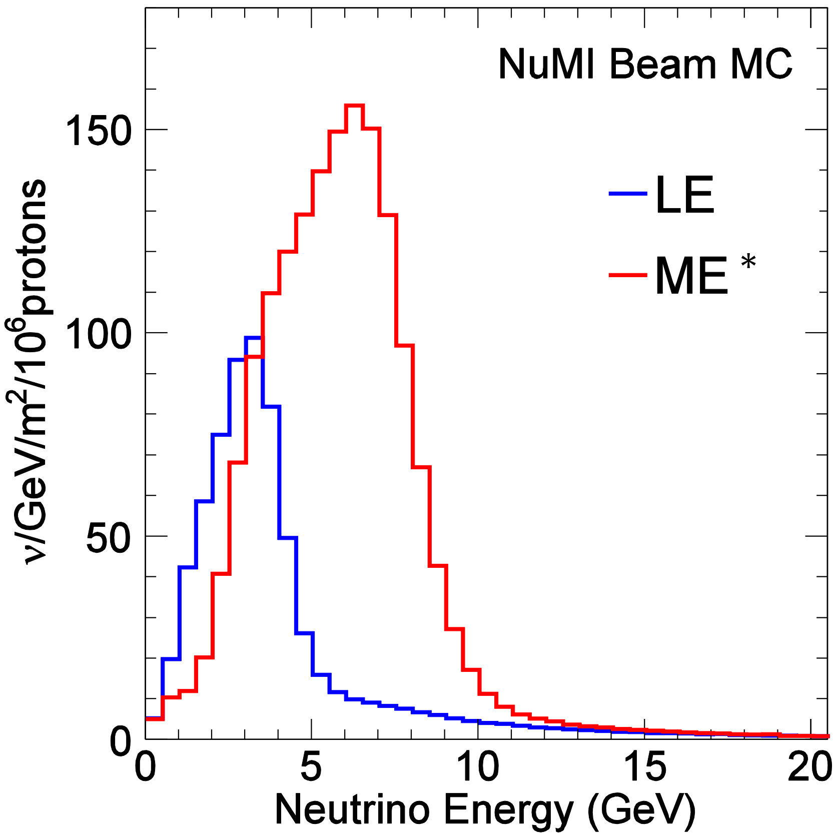
Outline

1. Overview & motivation
2. MINERνA detector
3. Flux determination
4. Event reconstruction
5. MINERνA test beam
6. CC inclusive analyses:
   - Neutrino energy spectra in the low (LE), medium (ME) and high energy (HE) beams.
   - Fe/Pb event rates versus muon energy.

MINERνA overview

MINERνA is a neutrino scattering experiment in the NuMI beamline at Fermilab, designed to measure neutrino cross-sections, final states and nuclear effects.

- Fe, Pb, C, liquid He and plastic targets.
- NuMI is an intense, broad spectrum, flexible and existing neutrino beam.
- Currently running in the low energy (LE) beam with MINOS, will continue in the medium energy (ME) beam with NOνA.



* LE target in ME position (not the NOνA ME flux).

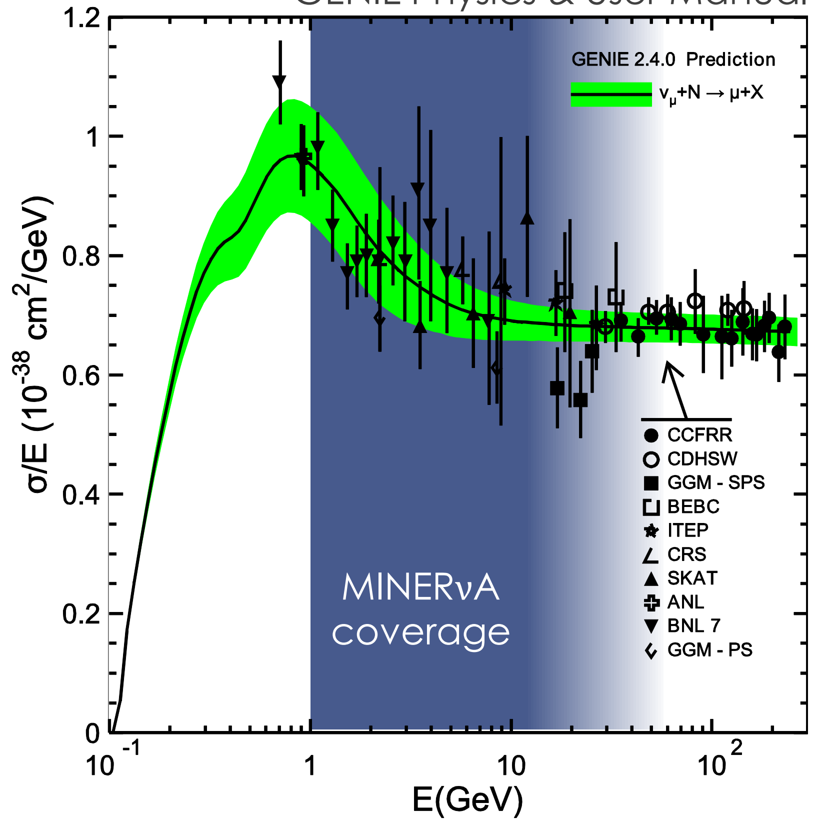
Physics motivation

Neutrino cross-sections and nuclear effects are a significant uncertainty in oscillation experiments.

- With two detectors, cross-sections do not completely cancel; the energy spectrum is not identical between near and far.
- E_ν is derived from $E_{visible}$, which is modified by final state interactions.

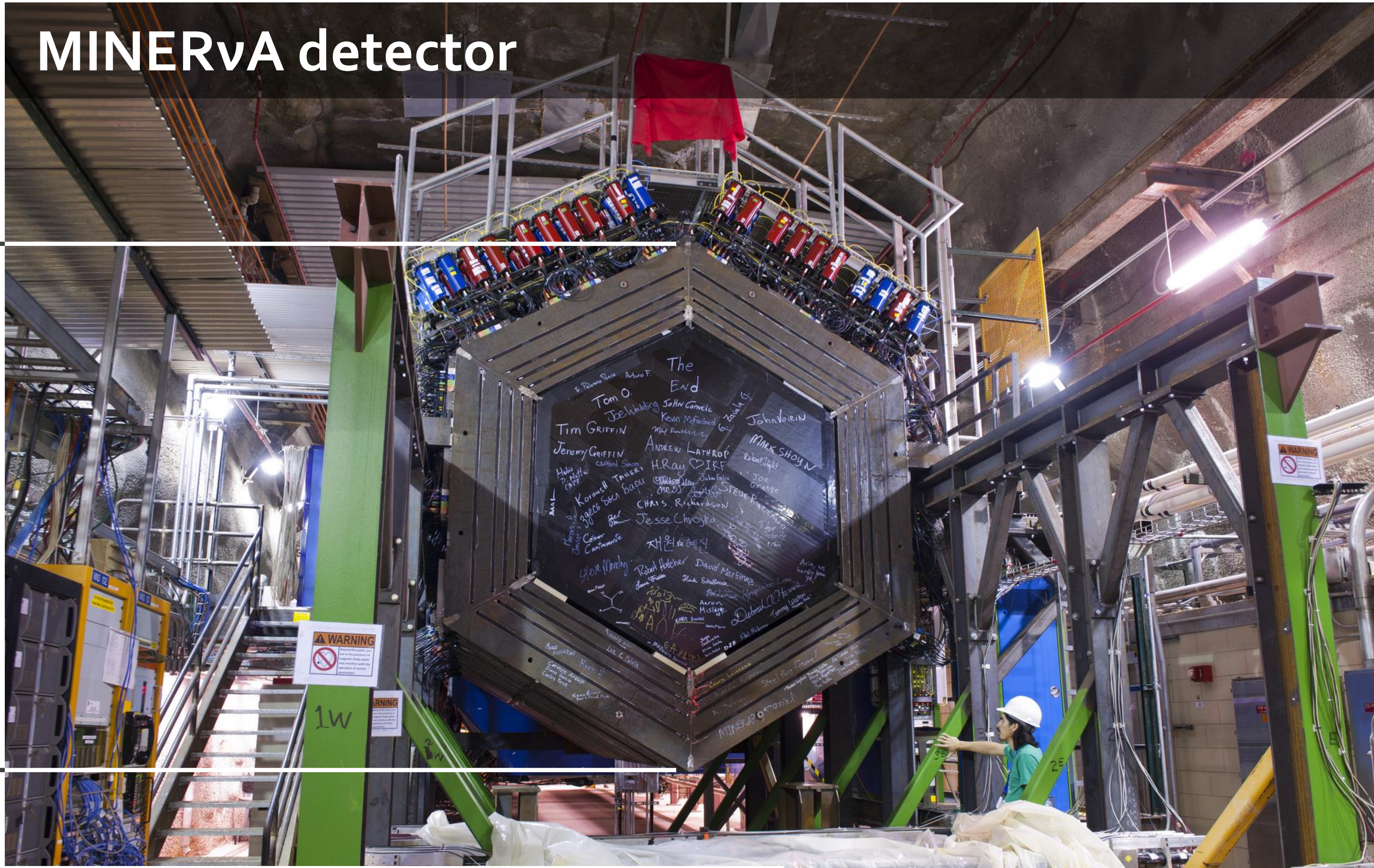
Neutrino scattering provides a unique probe of the nucleus, complementary to charged lepton scattering.

GENIE Physics & User Manual

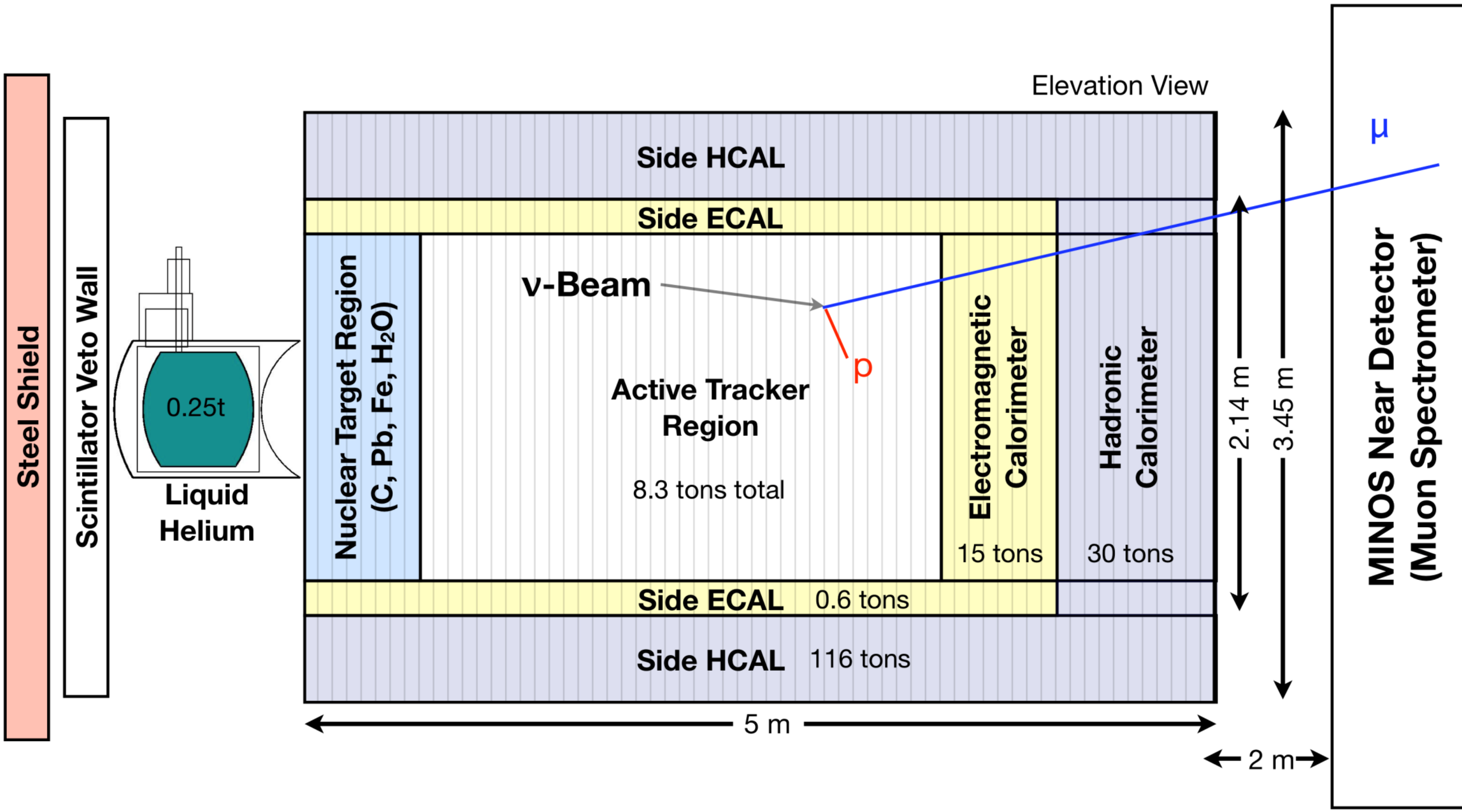


MINERνA detector

4m



17mm

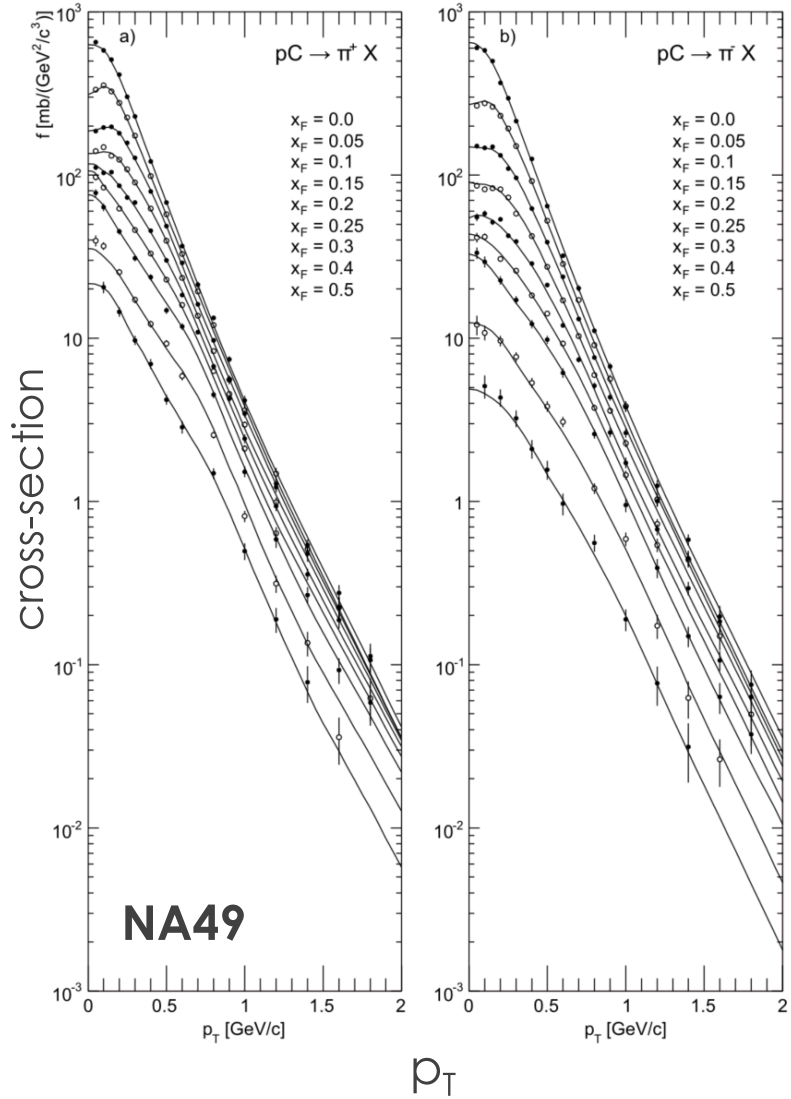

Elevation View
Steel Shield
Scintillator Veto Wall
0.25t
Liquid Helium
Side HCAL
Side ECAL
Nuclear Target Region (C, Pb, Fe, H_2O)
ν-Beam
p
μ
Active Tracker Region
8.3 tons total
Electromagnetic Calorimeter
15 tons
Hadronic Calorimeter
30 tons
Side ECAL 0.6 tons
Side HCAL 116 tons
5 m
2.14 m
3.45 m
2 m
MINOS Near Detector (Muon Spectrometer)

Flux determination

MINERνA uses three methods to determine the NuMI beam flux:

1. Leverage external hadron production data on (thin) carbon targets.
2. Muon monitors placed in the rock absorber downstream of the target.
3. Tune beam MC to match different configurations of the NuMI beam.

See M. Kordosky on August 4th, WG2.

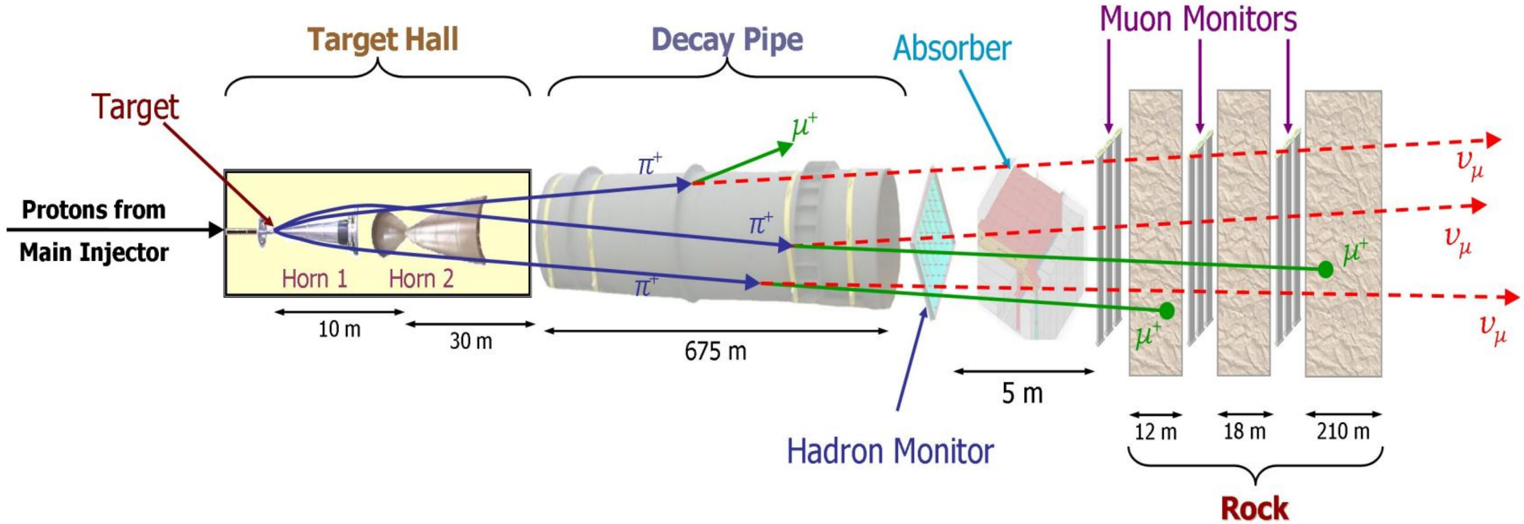


Eur. Phys. J. C **49**, 897 (2007) hep-ex/0606028

Muon monitors

Three ionization chambers placed in the rock absorber downstream of the target measure muon flux above an energy threshold increasing with distance.

- Provide a neutrino flux measurement independent of MINERνA or MINOS.
- Horn current scans allow for a continuous spectral measurement.

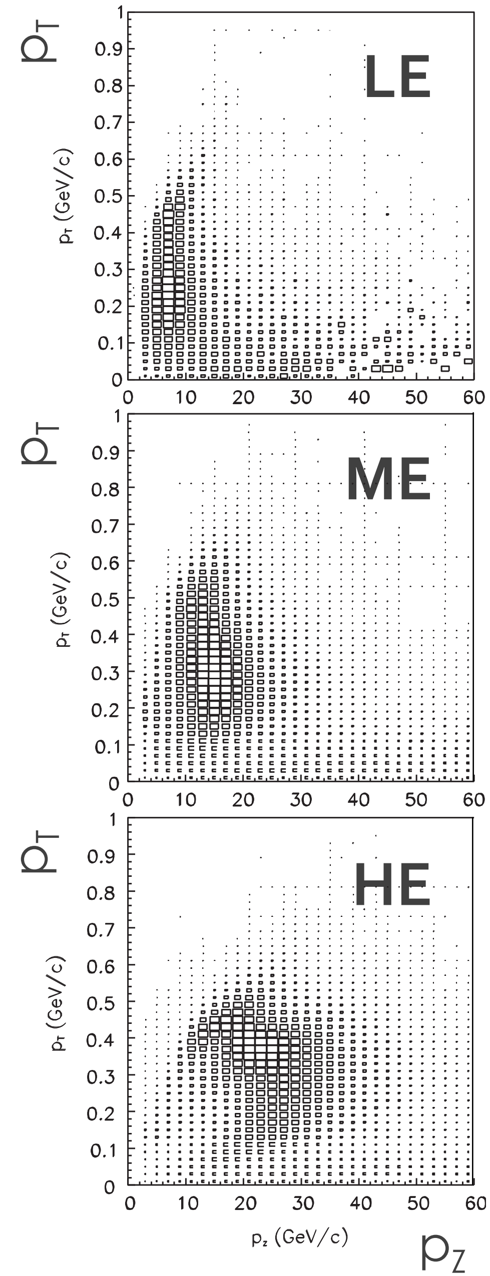


Beam MC tuning

The NuMI beam is reconfigurable; the neutrino energy can be selected by varying the position of the target and horns and the horn current.
ν or $\bar{\nu}$ is selected by the horn polarity.

The hadron momentum spectrum off the target is the largest uncertainty in the beam flux. By varying the beam settings, we can sample different regions of the hadron p_T/p_Z space, then fit our monte-carlo simulation to the data.

- Normalization: existing high energy (>10 GeV) experimental data.
- Shape: "standard candle" with little neutrino energy dependence (quasi-elastics of moderate Q^2 or low nu/W).

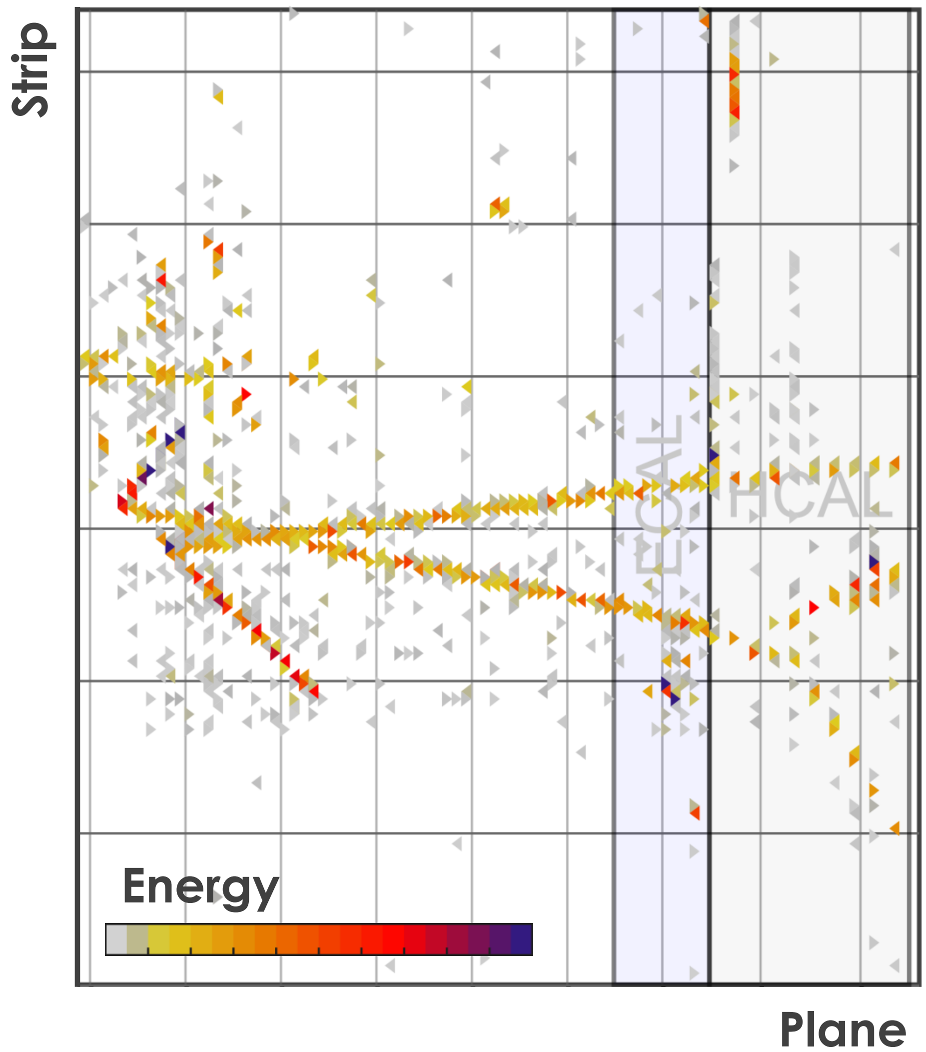


S. Kopp, *Phys. Rep.* **439**, 101 (2007)

Event reconstruction

MINERνA event reconstruction
is under active development.

See G. Perdue on August 3rd, WG2.



Event reconstruction

MINERνA event reconstruction
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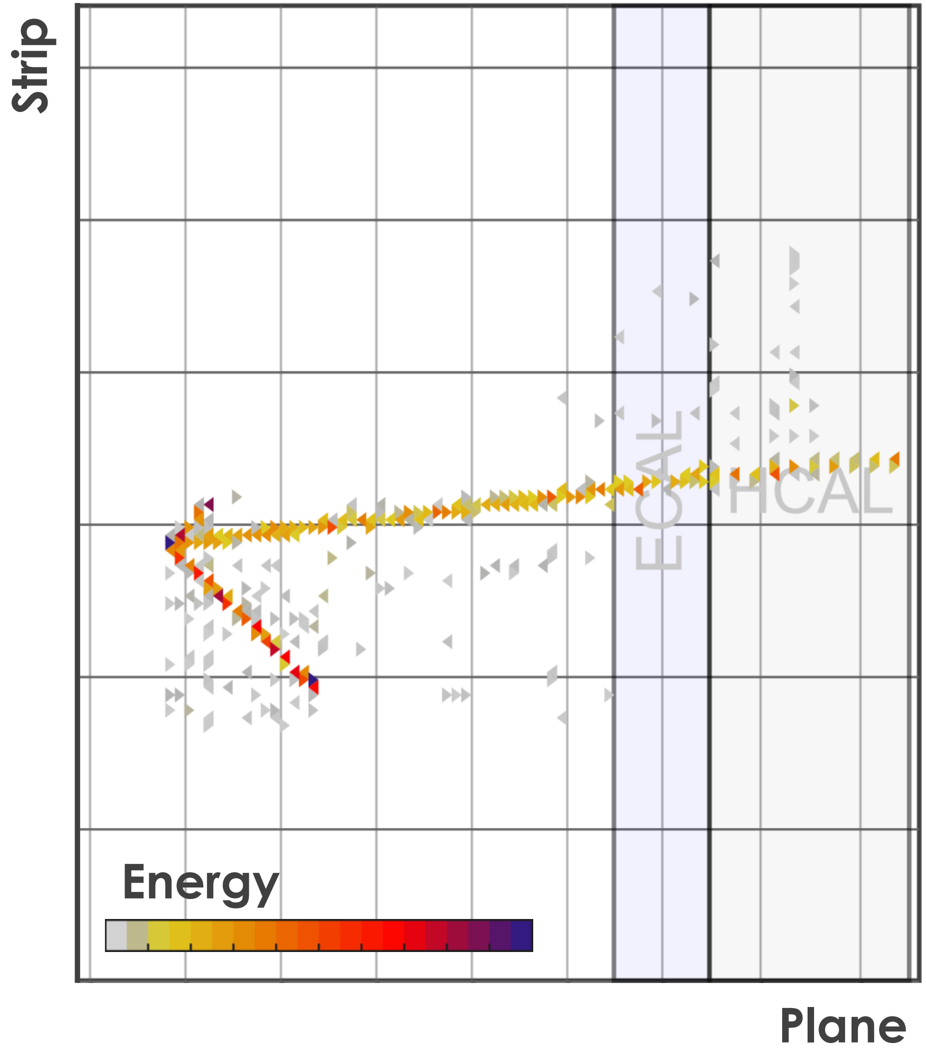
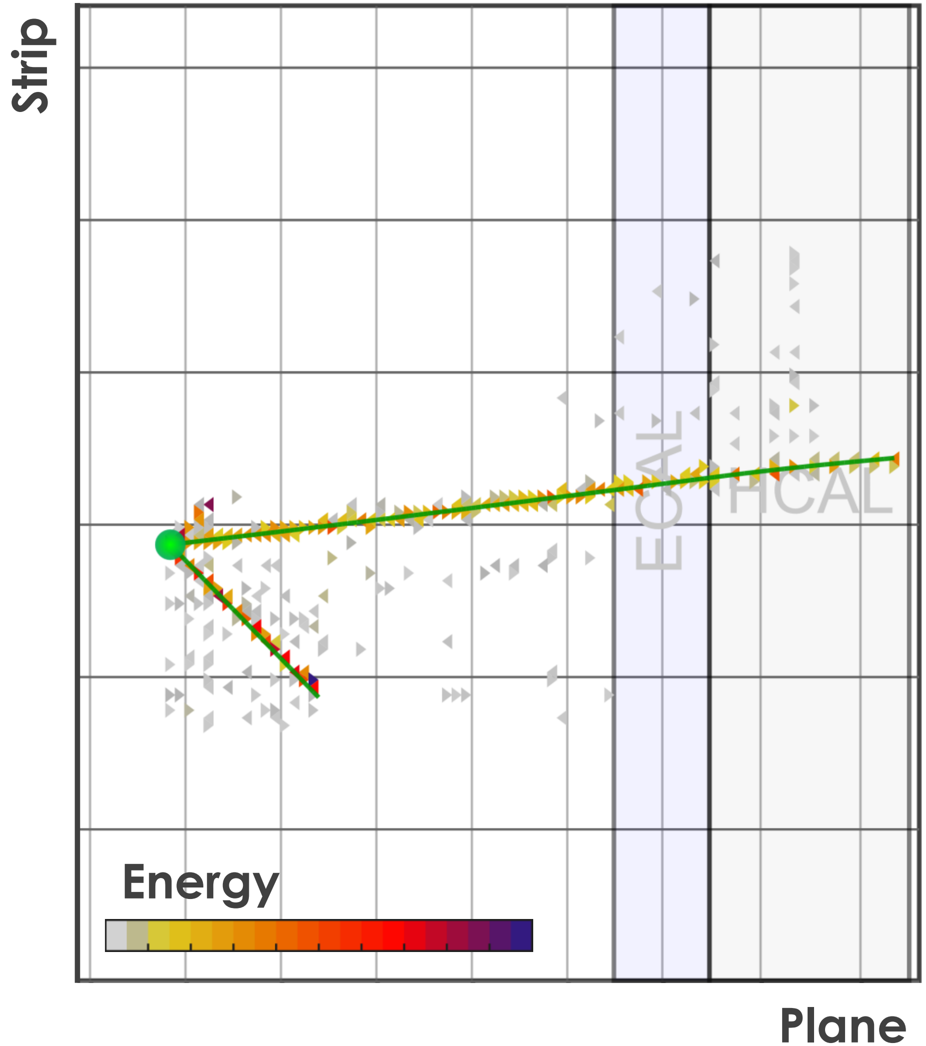
- Adjacent events within a single spill separated by hit timing.



Event reconstruction

MINERνA event reconstruction is under active development.

- Adjacent events within a single spill separated by hit timing.
- Muons identified and measured in MINOS by either range (6% resolution) or curvature (12%).
- In the future, include contained and side-exiting muons.
- Pion/proton tracks identified and measured by fitting the dE/dx profile.



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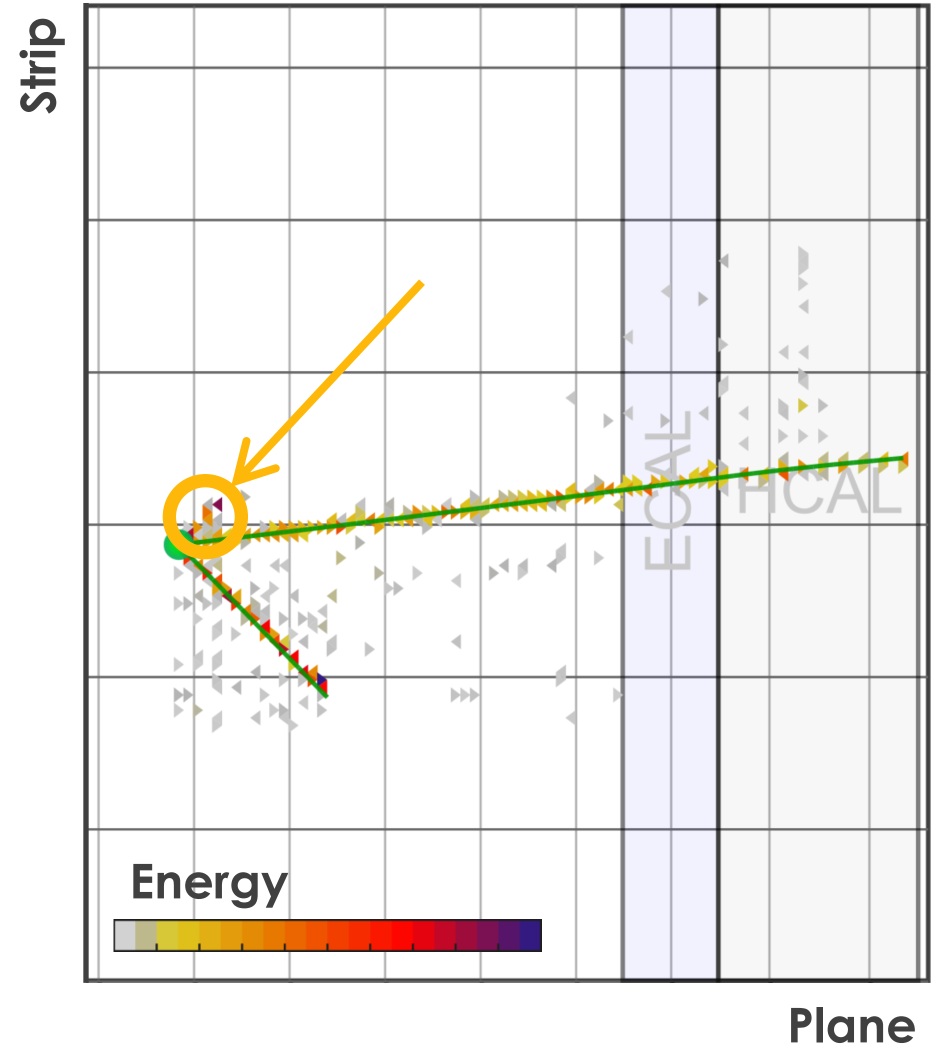
- Pion/proton tracks identified and measured by fitting the dE/dx profile.
- Showers localized and visible energy summed calorimetrically.



MINERνA test beam

To calibrate the absolute energy scale of the detector, a small, reconfigurable version was constructed and exposed to a measured beam.

- 40 scintillator planes of ~1m^2 active area can be interleaved with Fe/Pb absorber to emulate EM/hadronic calorimeters.
- Ran Summer 2010 at the Fermilab Test Beam Facility; calibrations and analysis in progress.

scintillator/ absorber

wire chamber

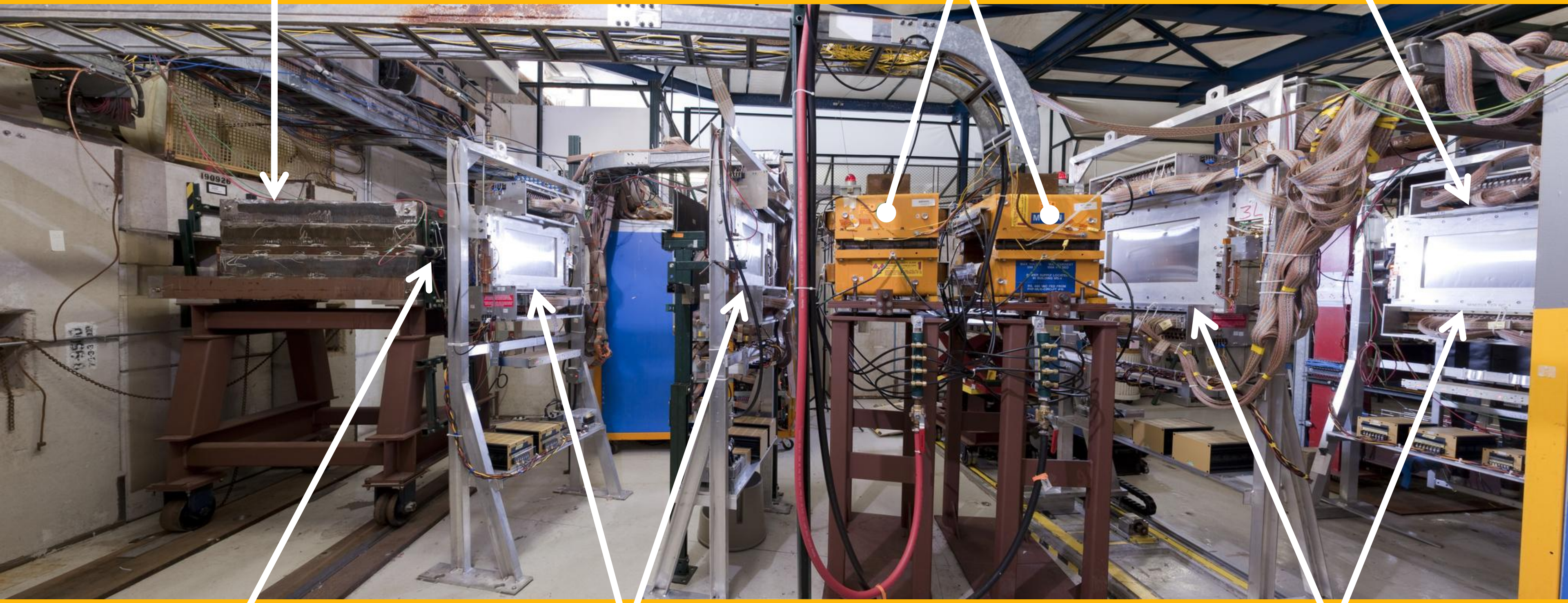
PMTs

cosmic trigger

target &
collimator

dipole
magnets

downstream TOF
(behind WC)

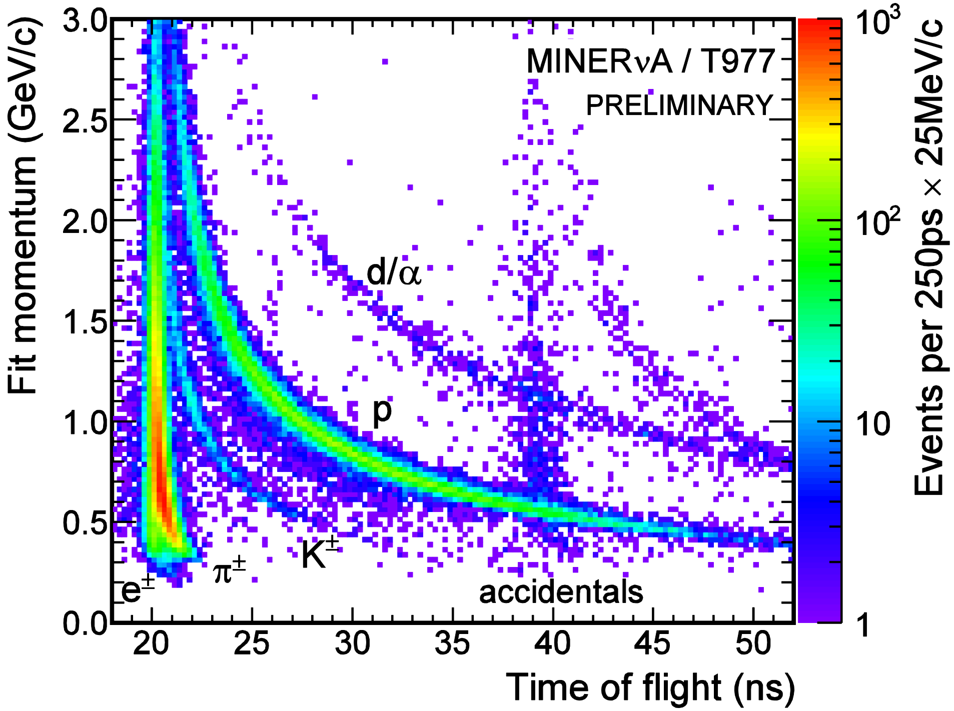


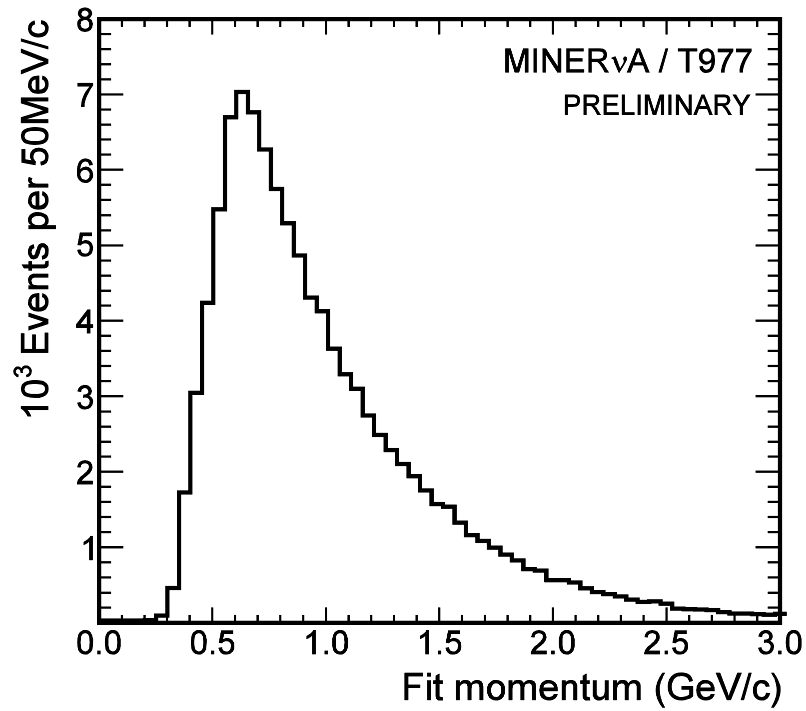
upstream
TOF

upstream
wire chambers

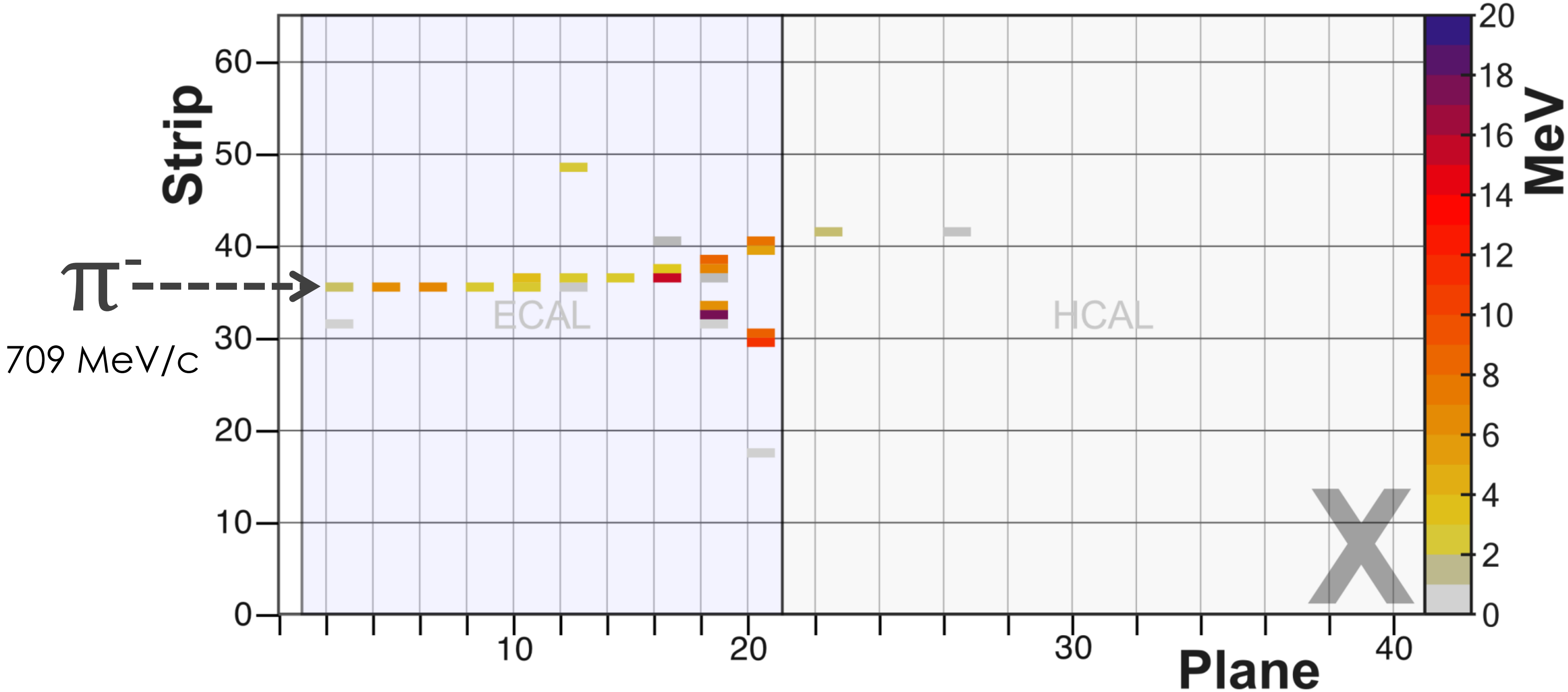
downstream
wire chambers

MINERνA and the Fermilab Test Beam Facility developed a new tertiary beamline to produce, identify and momentum-analyze low energy hadrons.





Summer 2010 test beam run, 107k events.



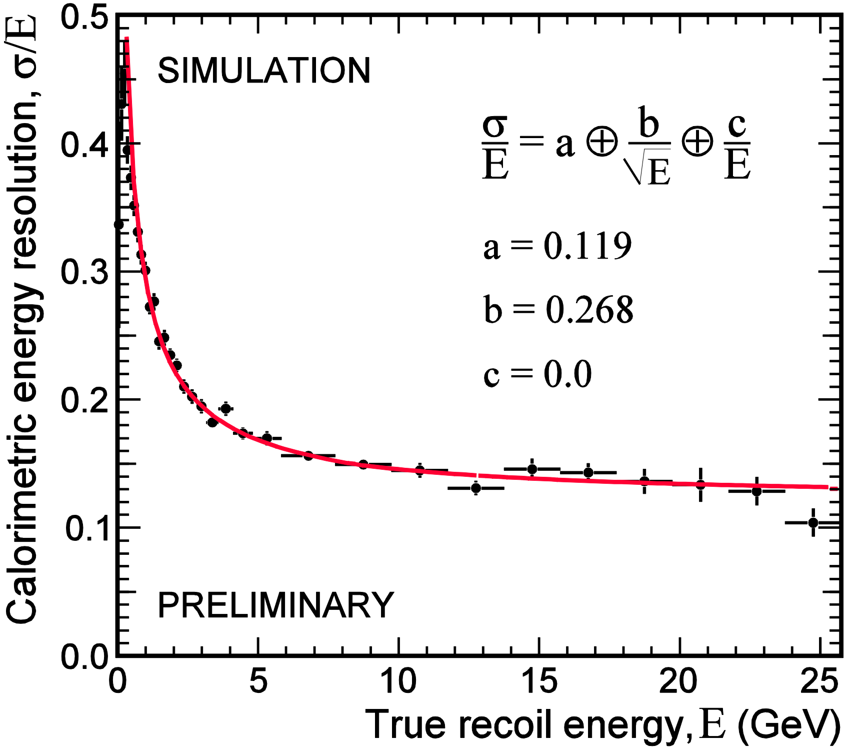
Test beam event display: a pion interacts and showers in the EM/hadronic calorimeter configuration.

Calorimetric energy resolution

Inclusive measurements often rely on calorimetry. Using simple calorimetry, the resolution for NC events simulated in the tracker is:

$$\frac{\sigma}{E} = 0.12 \oplus \frac{0.27}{\sqrt{E}}$$

- Sum visible energy in tracker and EM/hadronic calorimeters weighted to account for passive material.
- In the future, shower reconstruction and EM/hadronic compensation will improve energy resolution.



Towards CC inclusive cross-sections

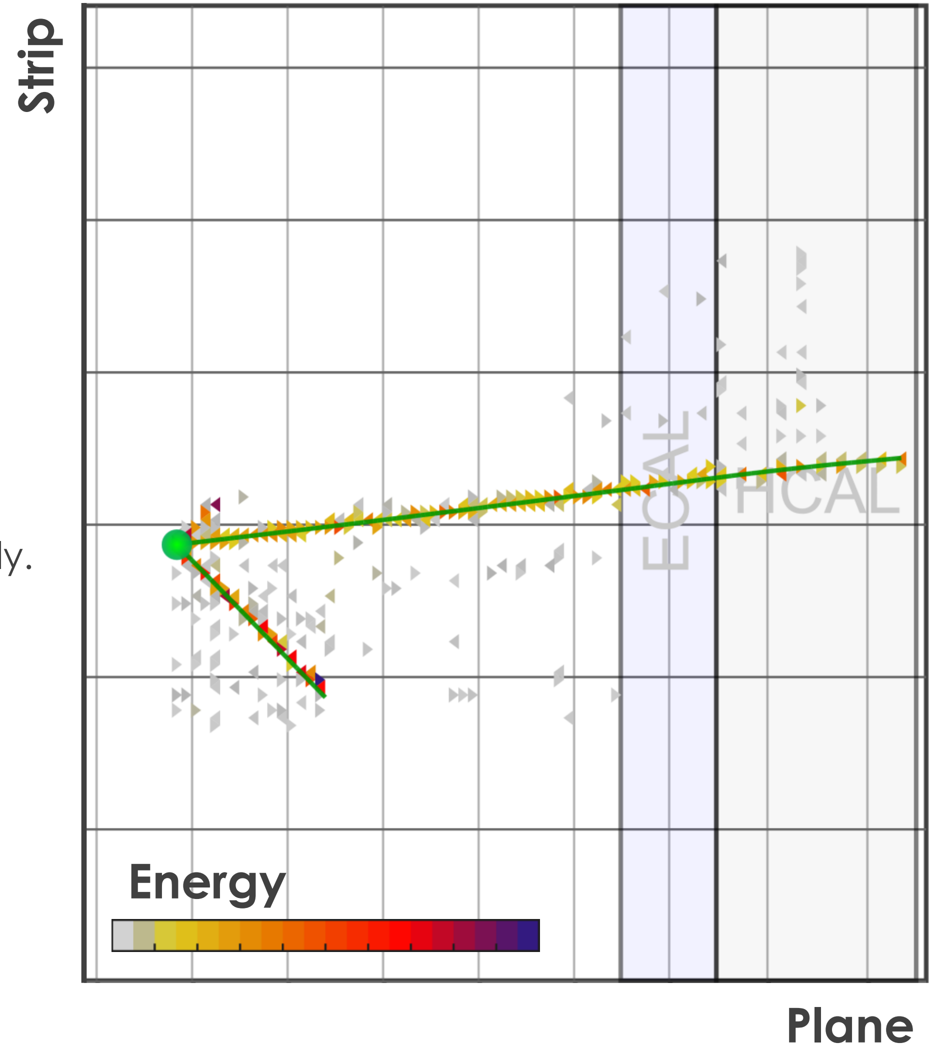
We present two analyses on the path towards CC inclusive cross-sections on plastic and the nuclear targets:

- Neutrino energy spectra in the low (LE), medium (ME) and high energy (HE) beams.
- Fe/Pb event rates versus muon energy.

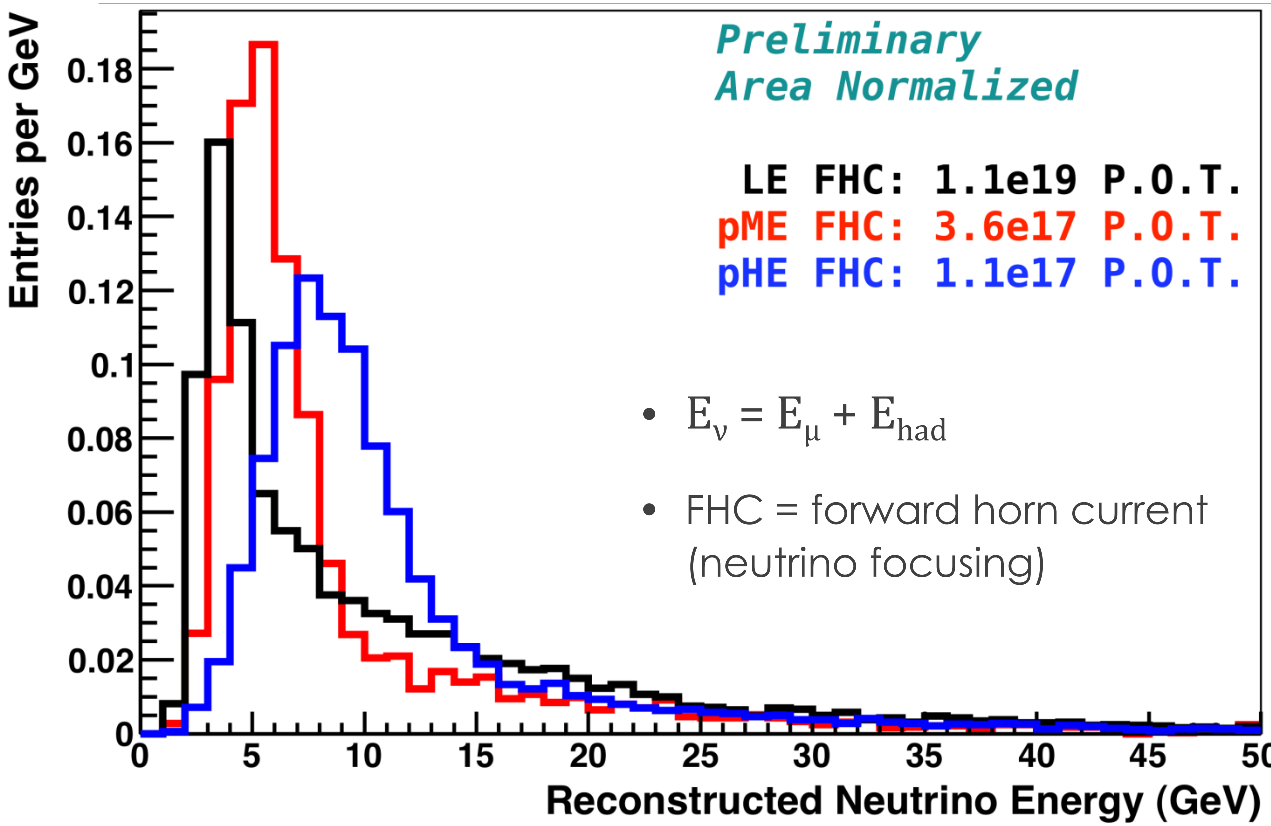
CC neutrino energy spectra

A demonstration of reconstruction techniques and the special runs taken for flux determination.

- $E_\nu = E_\mu + E_{had}$
- Muon matched to MINOS.
- Pion/proton tracks identified by dE/dx.
- Remaining energy summed calorimetrically.

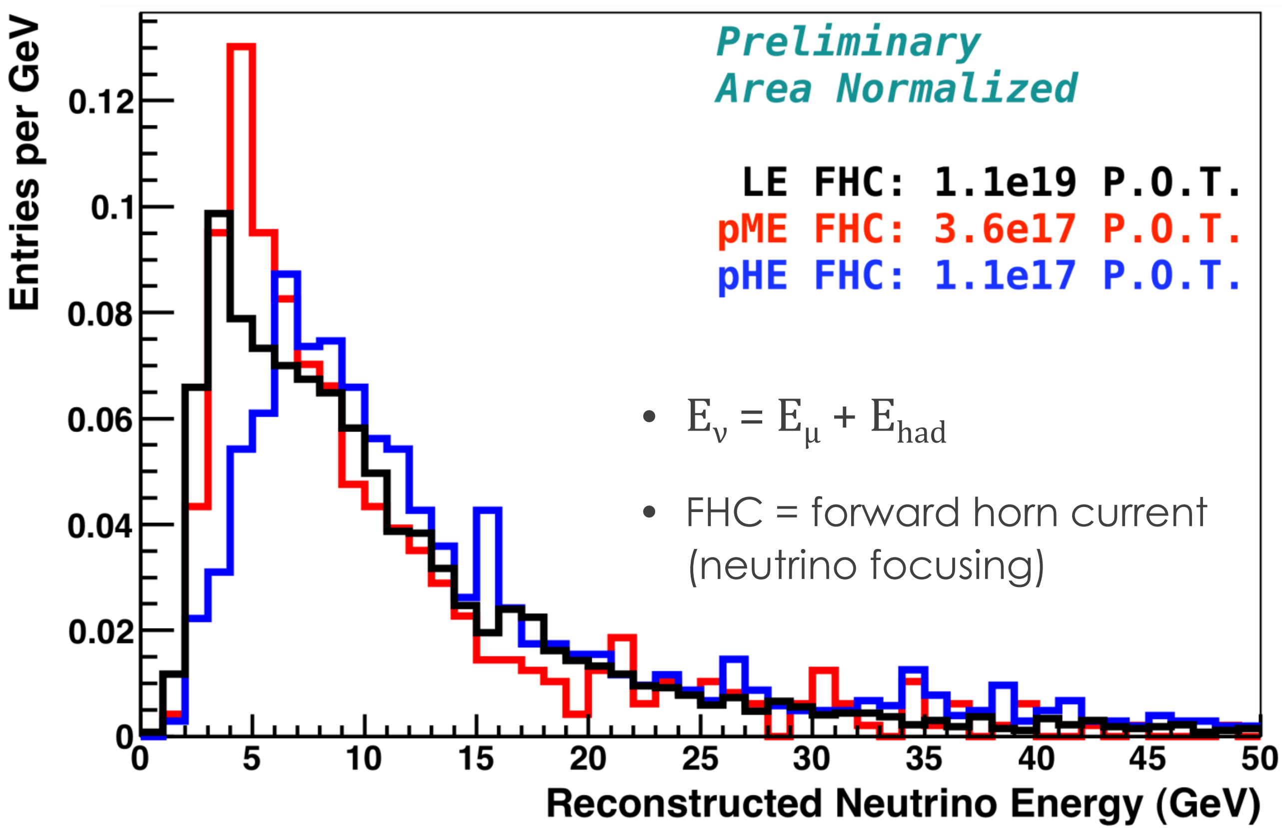


CC neutrino energy spectra



- $E_\nu = E_\mu + E_{had}$
- FHC = forward horn current (neutrino focusing)

CC anti-neutrino energy spectra

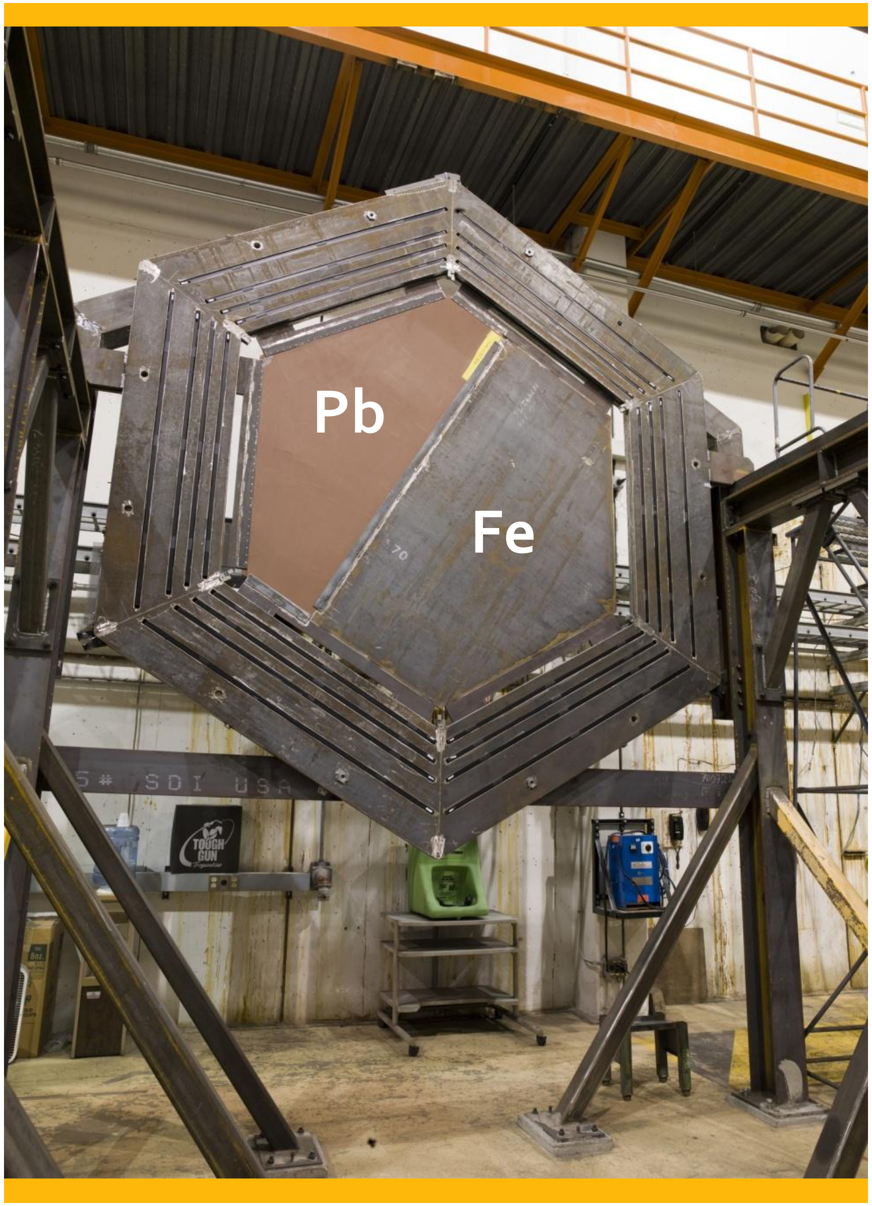


- $E_\nu = E_\mu + E_{had}$
- FHC = forward horn current (neutrino focusing)

~6% $\bar{\nu}$ content of the ν beam.

Nuclear targets

The upstream planes of MINERνA contain targets of Fe, Pb and C interleaved with scintillator, for measurements of nuclear effects.



Nuclear targets

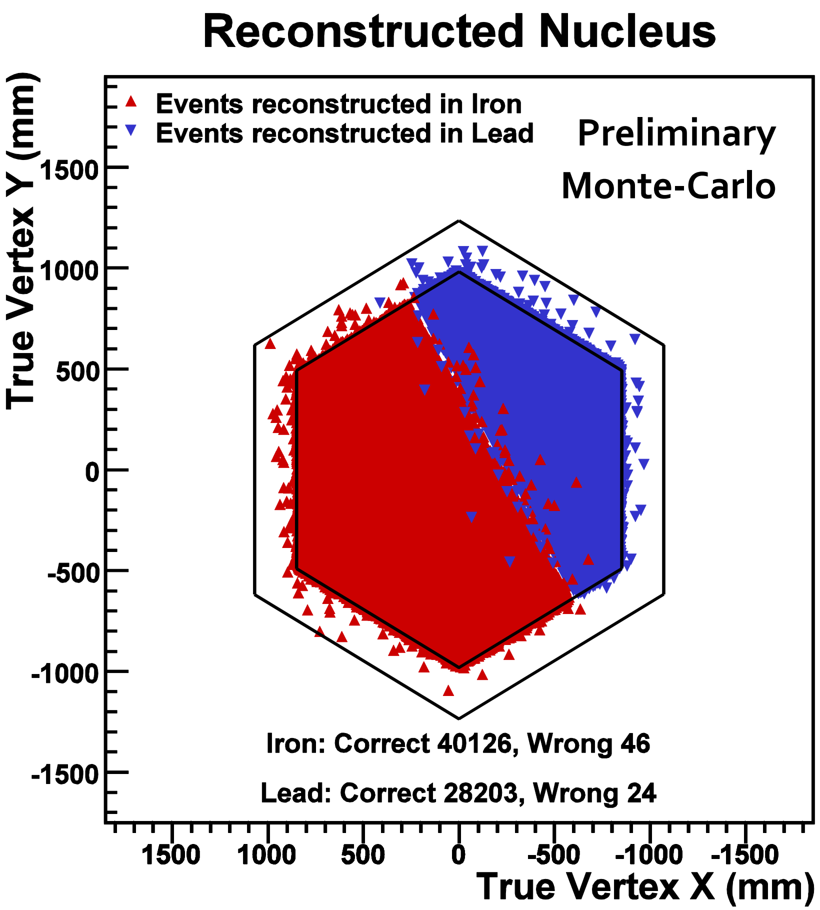
The upstream planes of MINERνA contain targets of Fe, Pb and C interleaved with scintillator, for measurements of nuclear effects.

- Cryostat installed, to be filled with liquid He soon.
- Proposal to run H/deuterium.
- H_2O target in development.

Fe/Pb CC event rates

Developing techniques on the most downstream target of Fe and Pb.

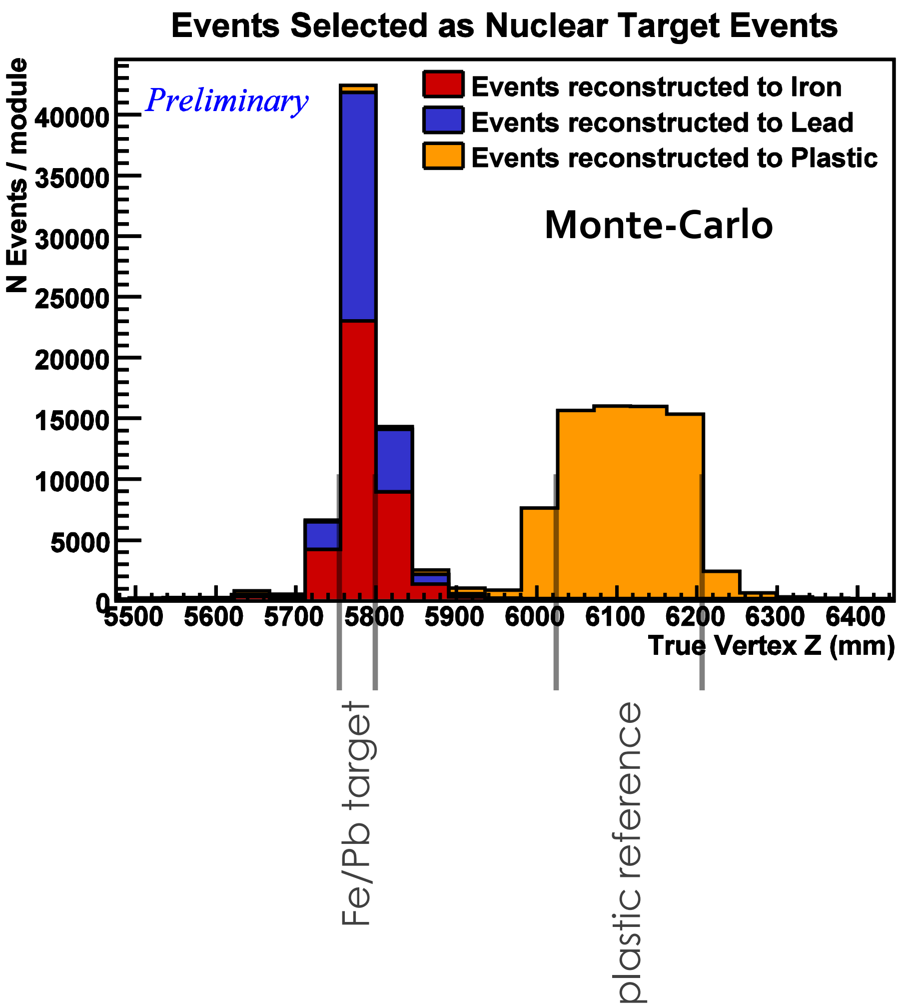
- Muon matched to MINOS with a projected vertex in the target.
- Fluka08 beam flux prediction (prior to MC tuning).
- Genie 2.6 event generator.



MC: 11.2e20 POT

Data: 9.1e19 POT

Fe/Pb CC event rates

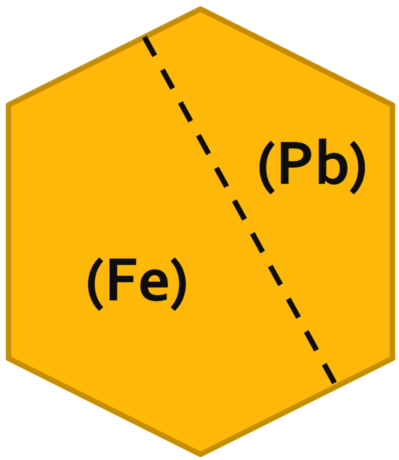


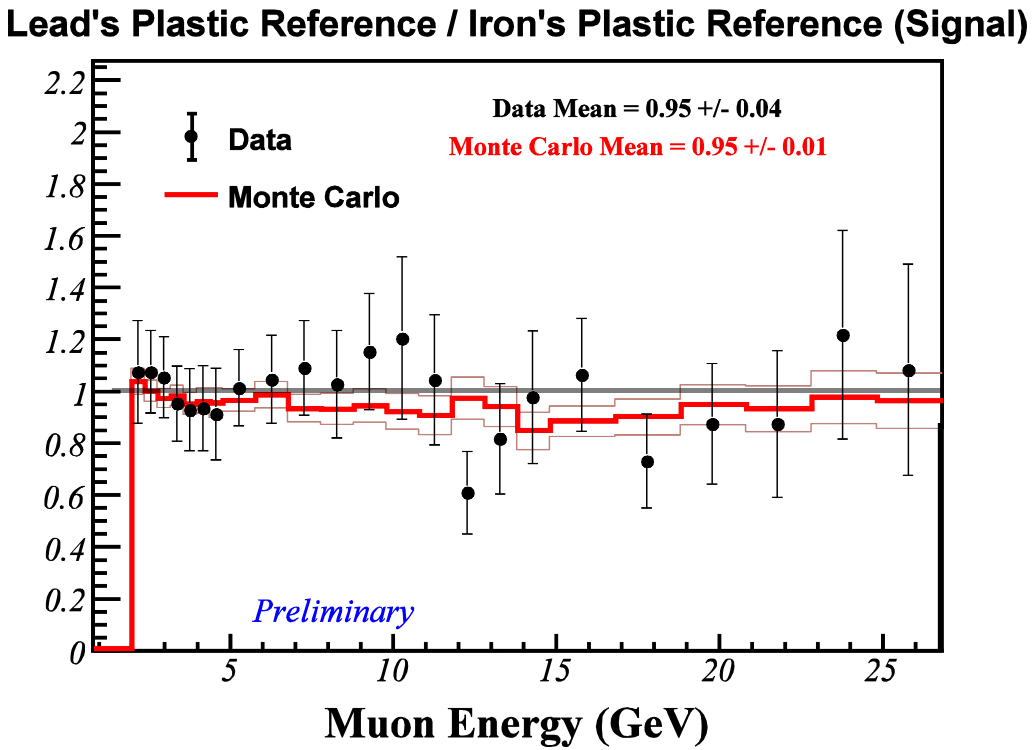
Backgrounds are introduced from events originating in the scintillator planes upstream and downstream of the passive target.

- Backgrounds and acceptance effects can be studied in data with an active plastic scintillator reference target.

Fe/Pb CC event rates

Simple ratios contain effects from MINOS acceptance and flux modeling.





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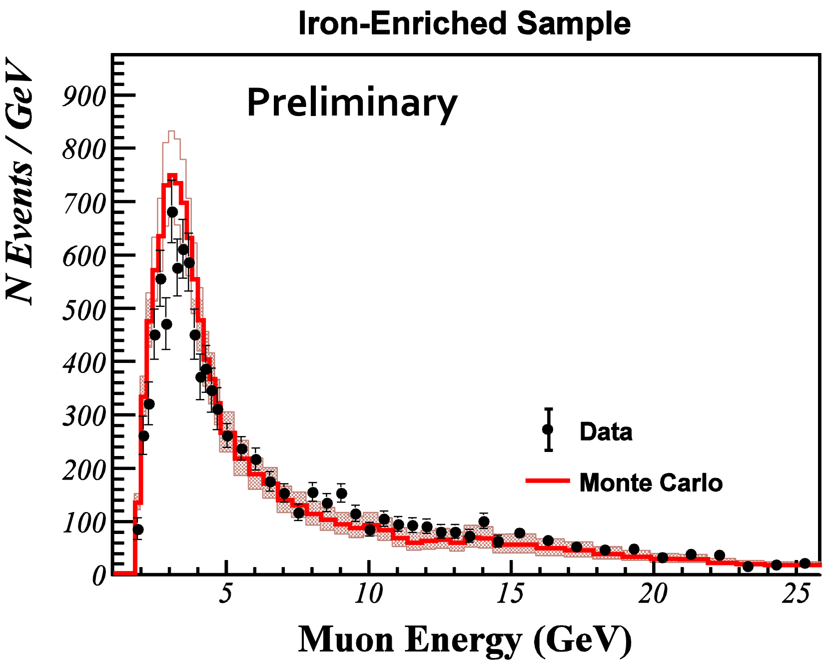

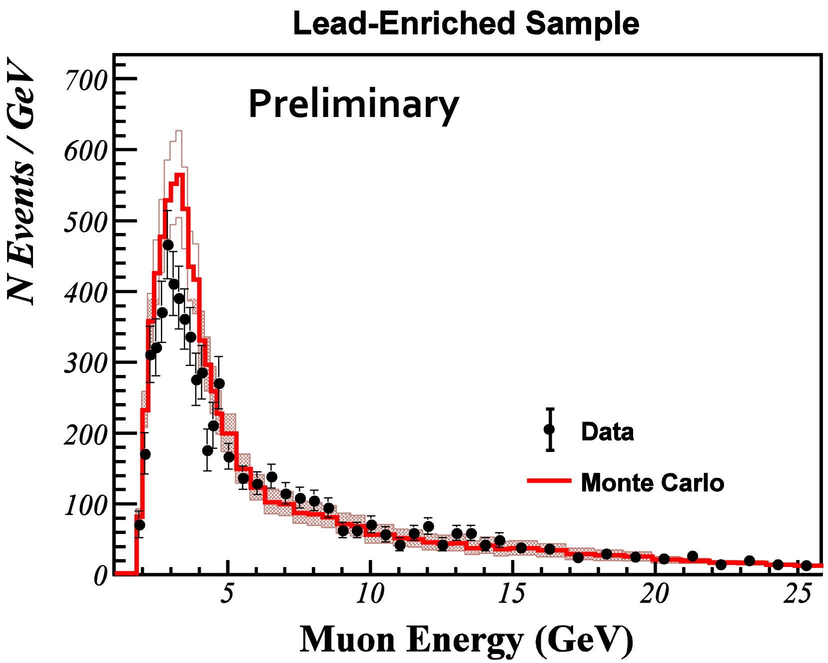

Discrepancies between data and MC result primarily from untuned flux model.

MC: 11.2e20 POT
Data: 9.1e19 POT

Summary

MINERνA will measure neutrino cross-sections, final states and nuclear effects on a variety of targets in the few-GeV region to reduce uncertainties in oscillation experiments and provide new understanding of the nucleus.

- Detector is operational and recording data.
- Reconstruction methods are under development.
- Analysis is underway.

Thank you

On behalf of the MINERνA collaboration, thank you to the accelerator division and NuMI specialists at Fermilab, the NuFact organizers and the audience.

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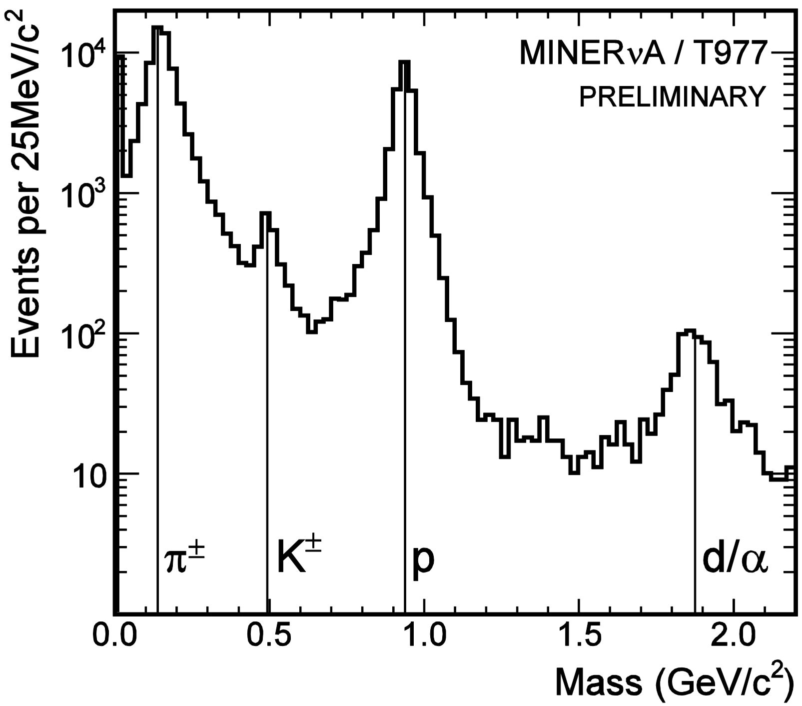
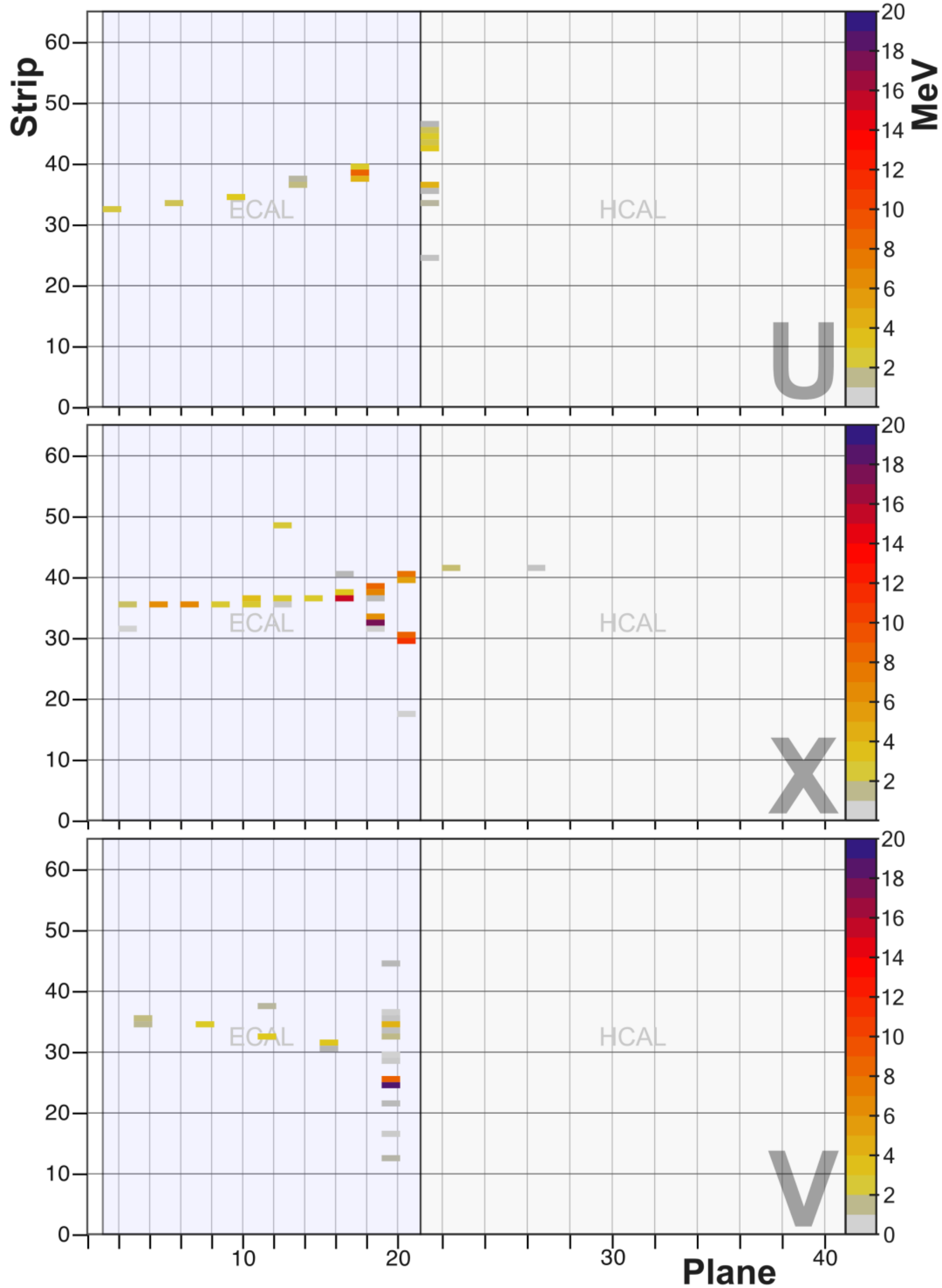
// backup



Summer 2010 test beam run, 107k events.


Strip
Plane
MeV
ECAL
HCAL
U
X
V
0
10
20
30
40
50
60
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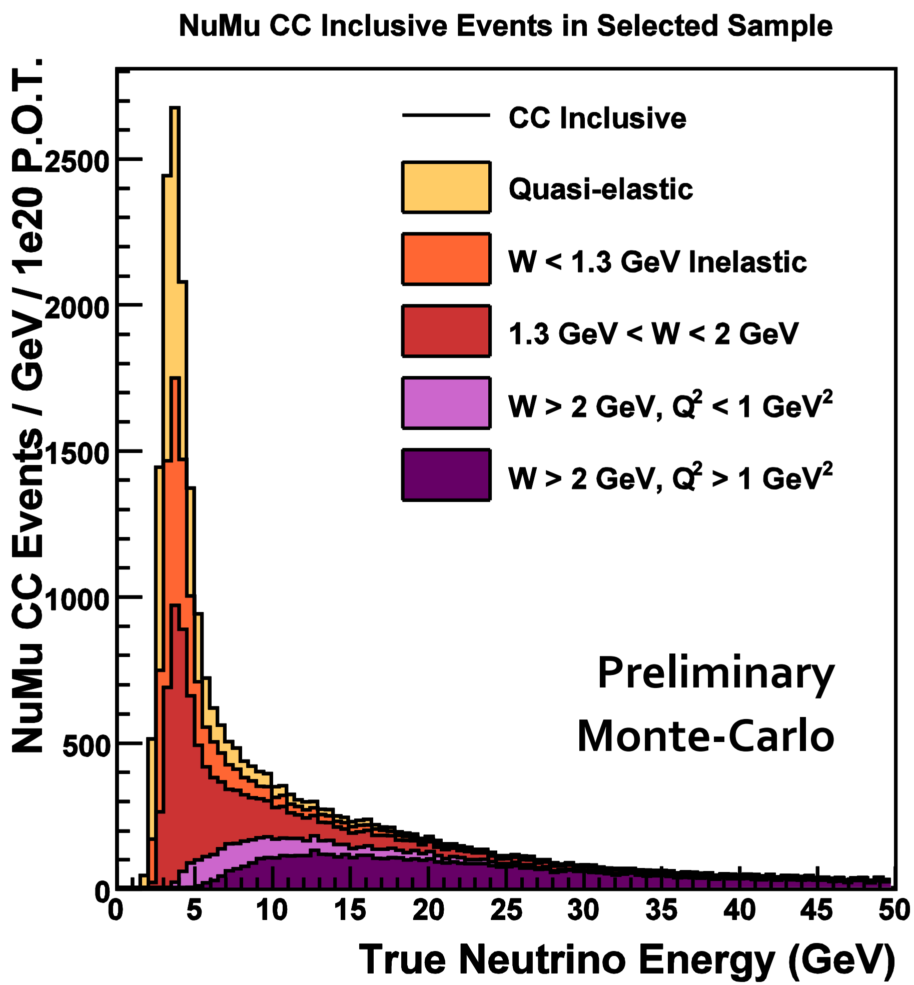
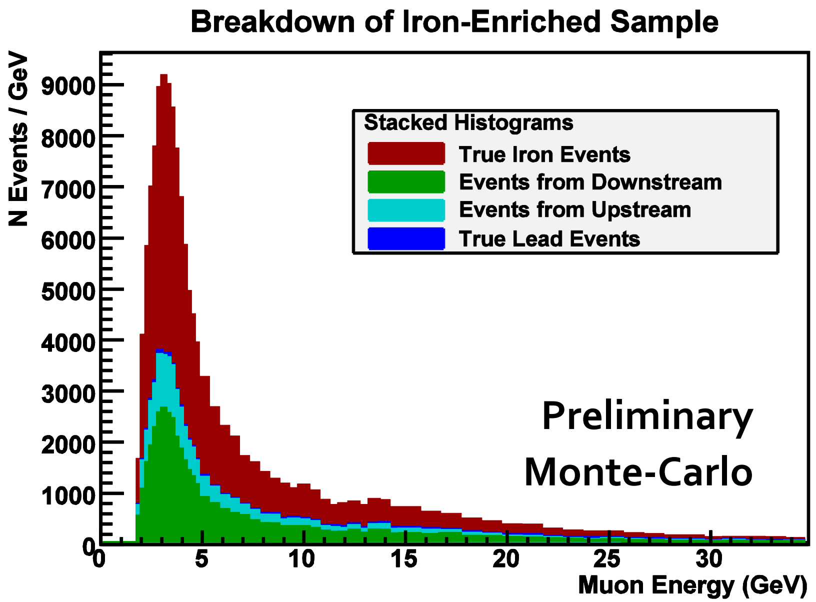
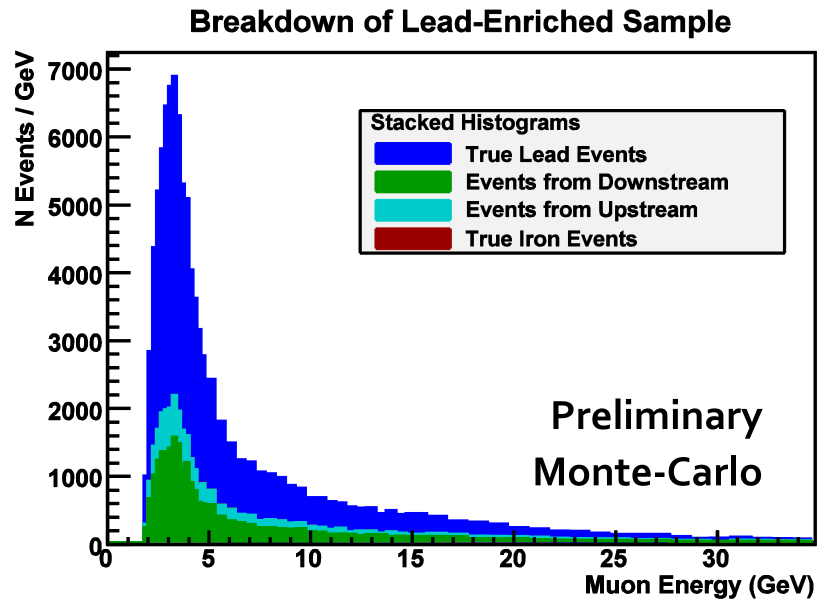

NuMu CC Inclusive Events in Selected Sample
NuMu CC Events / GeV / 1e20 P.O.T.
0
500
1000
1500
2000
2500
0
5
10
15
20
25
30
35
40
45
50
True Neutrino Energy (GeV)
CC Inclusive
Quasi-elastic
W < 1.3 GeV Inelastic
1.3 GeV < W < 2 GeV
W > 2 GeV, Q^2 < 1 GeV^2
W > 2 GeV, Q^2 > 1 GeV^2
Preliminary
Monte-Carlo


Breakdown of Iron-Enriched Sample
N Events / GeV
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
5
10
15
20
25
30
Muon Energy (GeV)
Stacked Histograms
True Iron Events
Events from Downstream
Events from Upstream
True Lead Events
Preliminary
Monte-Carlo


Breakdown of Lead-Enriched Sample
N Events / GeV
0
1000
2000
3000
4000
5000
6000
7000
0
5
10
15
20
25
30
Muon Energy (GeV)
Stacked Histograms
True Lead Events
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Events from Upstream
True Iron Events
Preliminary
Monte-Carlo